

## 5. Heavy Metals in Sediments

Heavy metal concentrations at each Chirag sample station were determined from 2 replicate sediment samples. Replicate values are given in Table 5.1.

**Table 5.1 Replicate Metal Concentrations ( $\mu\text{g}\cdot\text{g}^{-1}$ ) Chirag Survey 2010**

Station Number	Rep	As	Ba HNO <sub>3</sub>	Ba Fusion	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
1	1	18.3	19,563	25,677	0.80	23.3	17.8	18,517	0.03	398	27.2	48.6
	2	18.1	23,135	23,244	0.86	32.7	20.7	21,467	0.04	413	27.1	53.1
2	1	18.8	22,251	33,572	0.72	21.7	16.2	17,119	0.02	412	22.6	46.0
	2	19.0	23,770	28,864	0.43	46.6	23.1	28,598	0.05	466	26.8	76.7
7	1	16.6	14,120	15,184	0.33	52.9	43.4	30,061	0.05	552	31.6	224.7
	2	8.2	3,168	3,725	0.17	69.5	39.2	37,188	0.04	725	16.5	147.6
8	1	21.9	6,998	8,468	0.25	38.9	29.9	26,515	0.05	695	23.4	115.2
	2	18.5	5,683	7,084	0.25	29.5	17.5	20,945	0.04	449	18.9	65.2
9	1	11.4	25,324	28,798	0.79	35.5	17.9	22,499	0.04	406	23.7	58.9
	2	31.6	29,015	40,941	0.78	53.1	28.1	35,566	0.06	461	33.3	90.7
15	1	56.4	19,413	19,417	0.70	45.5	21.7	37,687	0.04	414	32.4	73.4
	2	179.3	18,240	23,671	0.27	58.3	44.2	80,544	0.05	681	34.1	129.8
16	1	16.1	9,181	14,389	0.33	39.0	35.5	21,121	0.08	768	27.2	61.4
	2	21.0	10,009	14,162	0.38	36.2	18.4	23,925	0.04	445	30.5	55.8
25	1	31.9	9,804	10,371	0.38	50.3	25.0	32,338	0.05	539	20.9	66.9
	2	22.4	8,604	9,418	0.27	55.4	25.4	32,630	0.05	505	75.2	77.3
33	1	23.2	18,456	21,838	0.53	38.3	18.5	27,198	0.04	419	24.0	57.5
	2	33.9	20,995	25,614	0.59	41.3	21.3	32,939	0.05	447	26.7	64.1
34	1	11.4	14,976	68,233	0.71	58.6	30.3	27,594	0.03	448	24.9	107.6
	2	14.7	27,810	28,280	0.63	56.6	19.7	28,339	0.03	486	35.8	79.8
35	1	20.2	33,773	40,911	0.64	48.5	33.8	28,998	0.05	657	43.0	111.8
	2	12.2	20,351	30,038	0.55	37.1	22.8	24,210	0.05	394	32.4	87.2
36	1	102.2	10,401	14,229	0.44	48.4	18.2	43,756	0.03	493	20.8	68.4
	2	40.7	9,125	13,821	0.40	45.0	16.6	33,631	0.02	482	20.1	63.1
37	1	59.7	27,216	34,465	0.73	29.2	18.9	36,119	0.02	415	33.3	95.7
	2	58.0	21,431	57,817	0.76	55.1	52.9	43,857	0.04	519	33.5	139.0
38	1	13.3	28,355	55,645	0.73	71.1	24.3	31,392	0.04	544	27.1	90.6
	2	11.3	32,899	34,954	0.64	45.7	29.9	21,646	0.06	373	29.2	76.3
39	1	18.2	27,217	31,846	0.55	24.8	12.1	18,996	0.03	344	24.7	43.9
	2	17.5	27,531	32,365	0.62	41.4	24.2	27,325	0.04	397	28.0	62.8
40	1	NA	NA	19,649	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	NA	29,764	NA	NA	NA	NA	NA	NA	NA	NA
41	1	NA	NA	14,874	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	NA	16,041	NA	NA	NA	NA	NA	NA	NA	NA

**Table 5.1 (Continued) Replicate Metal Concentrations ( $\mu\text{g}\cdot\text{g}^{-1}$ ) Chirag Survey 2010**

Station Number	Rep	As	Ba HNO <sub>3</sub>	Ba Fusion	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
42	1	NA	NA	9,981	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	NA	16,016	NA	NA	NA	NA	NA	NA	NA	NA
43	1	NA	NA	16,292	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	NA	11,265	NA	NA	NA	NA	NA	NA	NA	NA
44	1	NA	NA	15,495	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	NA	3,828	NA	NA	NA	NA	NA	NA	NA	NA
45	1	NA	NA	20,147	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	NA	16,073	NA	NA	NA	NA	NA	NA	NA	NA
46	1	39.0	25,889	44,124	0.82	56.5	24.7	30,372	0.05	606	27.2	70.3
	2	24.7	22,765	53,495	0.60	51.4	21.2	25,504	0.05	532	27.0	76.7
47	1	17.9	9,797	11,831	0.32	45.0	22.2	25,446	0.06	602	24.9	62.2
	2	19.4	9,635	15,540	0.38	46.5	24.4	25,203	0.06	618	26.5	80.4
48	1	25.7	12,743	13,918	0.44	53.0	24.9	31,397	0.07	495	23.3	72.3
	2	8.2	3,841	4,236	0.15	40.4	18.0	21,418	0.04	371	11.0	53.3
49	1	17.3	5,047	5,484	0.19	49.8	19.3	27,968	0.03	594	14.6	54.5
	2	12.5	8,785	9,621	0.24	48.4	19.5	24,773	0.03	415	17.0	58.5
50	1	21.8	8,575	10,721	0.28	62.2	20.3	33,745	0.05	565	18.9	68.5
	2	19.8	8,451	8,815	0.32	39.7	14.5	26,275	0.03	493	14.5	48.5
51	1	NA	NA	8,454	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	NA	7,691	NA	NA	NA	NA	NA	NA	NA	NA
52	1	17.6	6,366	10,987	0.28	30.2	12.5	18,614	0.03	324	15.7	37.0
	2	16.9	3,144	3,350	0.18	66.2	21.3	30,799	0.03	618	14.9	63.8
53	1	35.3	15,295	16,326	0.42	42.9	17.2	31,531	0.04	466	24.1	59.1
	2	20.6	6,960	7,360	0.28	61.2	20.8	34,898	0.03	629	17.8	67.6
54	1	22.1	4,161	5,607	0.25	56.8	21.6	37,552	0.03	497	15.8	63.4
	2	17.6	12,001	14,121	0.46	39.2	15.7	24,702	0.03	449	16.5	46.2
55	1	28.3	18,599	19,934	0.59	30.4	15.6	23,657	0.04	417	28.8	49.0
	2	23.9	14,993	17,741	0.53	38.3	17.7	27,028	0.05	446	23.8	59.1
56	1	53.9	6,853	9,286	0.29	58.9	21.5	39,073	0.05	754	20.8	79.1
	2	11.2	1,740	2,025	0.12	74.1	22.7	34,365	0.05	683	16.6	76.9
57	1	11.2	2,210	3,553	0.11	90.6	30.8	39,052	0.05	618	17.7	87.0
	2	16.0	8,181	11,071	0.32	39.2	14.9	24,576	0.05	485	17.8	51.1
	Min	8.2	1,740	2,025	0.11	21.7	12.1	17,119	0.02	324	11.0	37.0
	Max	179.3	33,773	68,233	0.86	90.6	52.9	80,544	0.08	768	75.2	224.7
	Median	19.2	13,431	15,517	0.43	46.1	21.3	28,154	0.04	485	24.4	67.2
	Mean	27.4	15,093	19,724	0.46	47.1	23.3	29,820	0.04	508	25.2	75.5
	Std Dev	27.1	8,933	14,279	0.21	13.7	8.2	9,640	0.01	110	9.7	31.7
	%CV	99	59	72	46	29	35	32	27	22	38	42

NA: No Analysis

## 5.1. Results

Initial examination of the replicate data indicates poor replicate agreements for a number of elements at the majority of stations.

Replicate arsenic concentrations ranged from  $8.2\mu\text{g.g}^{-1}$  at station 48R2 to  $179.3\mu\text{g.g}^{-1}$  at station 15R2. A high concentration of  $102.25\mu\text{g.g}^{-1}$  was also observed at station 36R1, with the next highest concentration being  $59.7\mu\text{g.g}^{-1}$ . The median and mean concentrations were 19.2 and  $27.4\mu\text{g.g}^{-1}$  respectively and variation between samples was high with a CV of 99%.

Arsenic concentrations varied between replicates at a number of stations. The highest variation was recorded at stations 15 and 36 where the highest concentrations were recorded.

All samples were analysed for total barium (fusion). This was carried out to identify the extent of contamination from drilling discharges as barite in drilling fluids interferes with the determination of  $\text{HNO}_3$  extracted Ba. Replicate concentrations ranged from  $2,025\mu\text{g.g}^{-1}$  at station 56R2 to  $68,233\mu\text{g.g}^{-1}$  at station 34R1. The respective median and mean concentrations were 15,517 and  $19,724\mu\text{g.g}^{-1}$  and the CV was high at 94%.

The replicate agreement for total Ba was poor at a number of stations, with the greatest variation being recorded at stations 34, 37 and 38. Concentrations at these stations were relatively high, ranging from  $>28,000$  to  $>55,000$ .

Nitric acid ( $\text{HNO}_3$ ) extracted Ba as a % of total Ba was generally high throughout averaging at 79%. The lowest proportion was recorded at station 34R2, 37R2, 38R1, and both replicates at station 46 where  $\text{HNO}_3$  extraction accounted for 22, 37, 51, 59 and 43% of total Ba respectively. The combination of higher total Ba concentrations and low  $\text{HNO}_3$  extraction at these positions may indicate the presence barite from discharged drilling fluid or drill cuttings.

Previous ACG regional surveys which sample locations outside possible platform influence have recorded background total Ba concentrations up to  $16,000\mu\text{g.g}^{-1}$  in 2006,  $\sim 8000\mu\text{g.g}^{-1}$  in 2008 and  $\sim 17,000$  in 2010.

Figure 5.1 below gives the distribution plot of average concentrations for total Ba (table 5.2). This highlights the  $17,000\mu\text{g.g}^{-1}$  contour which gives the maximum background concentration from the 2008 ACG Regional Survey. This suggests that the footprint of elevated Ba concentrations include stations 1500m NE, 500m N, E & SW, 750m W and 250m S of the platform.

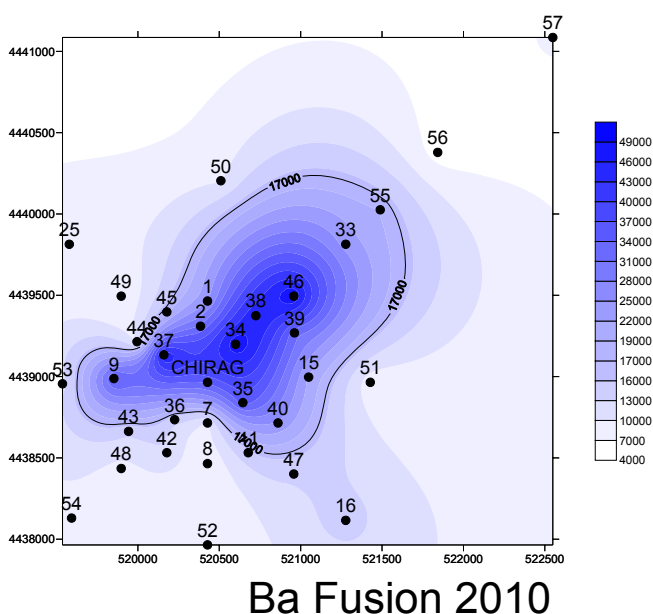


Figure 5.1 Average Ba Fusion Contour Plot Chirag Survey 2010

Cadmium replicate agreement was generally moderate to good. The greatest within station variation was recorded at stations 15, 2 and 48.

Replicate cadmium concentrations ranged from  $0.11\mu\text{g.g}^{-1}$  at station 57R1 to a maximum of  $0.80$  and  $0.86\mu\text{g.g}^{-1}$  at station 1. The respective median and mean concentrations were  $0.43$  and  $0.46\mu\text{g.g}^{-1}$  and the CV indicated a moderate variation at 46%. The range, median and mean results were similar to those recorded on the 2006 and 2008 surveys. Results from the 2010 ACG Regional survey recorded a maximum of  $0.64\mu\text{g.g}^{-1}$  which was observed in samples taken ~5000m north of the Chirag platform.

The concentration of chromium in replicate samples ranged from  $21.7$  to  $90.6\mu\text{g.g}^{-1}$  at stations 2R1 and 57R1 respectively. The median and mean concentrations were  $46.1$  and  $47.1\mu\text{g.g}^{-1}$  and the variation between samples was moderate with a CV of 29%.

Replicate copper concentrations ranged from  $12.1\mu\text{g.g}^{-1}$  at station 39R1 to  $52.9\mu\text{g.g}^{-1}$  at station 37R2 with respective median and mean concentrations of  $21.3$  and  $23.3\mu\text{g.g}^{-1}$  and a %CV of 35%.

The concentration of mercury in replicate samples ranged from  $0.02\mu\text{g.g}^{-1}$  at stations 2R1, 36R2 and 37R1 to a maximum of  $0.08\mu\text{g.g}^{-1}$  at station 16R1. The median and mean concentrations were  $0.04$  to  $0.08\mu\text{g.g}^{-1}$  and the %CV was moderate at 27.

Iron concentrations in replicate samples ranged from  $17,119\mu\text{g.g}^{-1}$  at station 2R1 to  $80,544\mu\text{g.g}^{-1}$  at station 15R2. Respective median and mean concentrations were  $28,154$  and  $29,820\mu\text{g.g}^{-1}$  and the CV of 32% indicates a moderate variation between samples.

A moderate to low variation between samples was recorded for manganese, with a CV of 22%. The median and mean concentrations were  $485$  and  $508\mu\text{g.g}^{-1}$  with a range of  $324\mu\text{g.g}^{-1}$  at station 52R1 to a maximum of  $768\mu\text{g.g}^{-1}$  at station 16R1.

Variation in lead concentrations was moderate with a %CV of 38. Concentrations ranged from  $11.0\mu\text{g.g}^{-1}$  at station 48R2 to  $75.2\mu\text{g.g}^{-1}$  at station 25R2. The highest concentration of  $75.2$  was particularly high, with the next highest concentration being  $43.0$  at station 35R1. The median and mean concentrations were  $24.4$  and  $25.2\mu\text{g.g}^{-1}$ .

Zinc concentrations in replicate samples ranged from  $37.0\mu\text{g.g}^{-1}$  at station 52R1 to  $224.7\mu\text{g.g}^{-1}$  at station 7R1. A high concentration of  $147.6$  was also present in the second replicate at station 7. The respective median and mean concentrations were  $67.2$  and  $75.5\mu\text{g.g}^{-1}$  and the % CV was moderate at 42.

Figure 5.2 below gives the distribution plots of average concentrations for each element (table 5.2). As noted there was variation between replicate samples at a number of stations which will increase the confidence limit of the mean values.

Examination of the distribution plots indicate that, although patchy, the distribution of Zn and Cu are similar with higher concentrations at stations 7, 37 and 15. Although not as distinct, Mn and Cr exhibit a similar distribution.

The distribution of As and Fe are very similar with the highest concentrations present at station 15, 750m to the east of the platform and stations 36 and 37, located 250m to the northwest and southwest of the platform. Examination of the replicate data for stations 15 and 36 indicates that the higher concentration of As and Fe were present in the same sample.

A high Fe and As concentration was also present in 2008 at station 50 to the far north of the survey area. Separate studies within the ACG contract area have identified an arseno-ferrous mineral, the presence of which results in particularly high concentrations of As and Fe. Although visual examination of the samples from stations 15, 37 and 36 failed to identify the presence of this mineral, the distinctive results, particularly at stations 15 and 36, strongly suggest that this arseno-ferrous mineral is present at these locations.

Similarities are also evident in the distribution of both extracted forms of Ba and Cd. Concentrations of these elements are highest at stations directly to the north, east and west of the platform and at stations extending to the north east.

The distribution plot for Hg indicates that the highest concentrations were present at contiguous stations 47 and 16, located 750m and 1250m to the southeast of the platform. Low concentrations were present at stations directly to the northeast, north, northwest and southwest of Chirag.

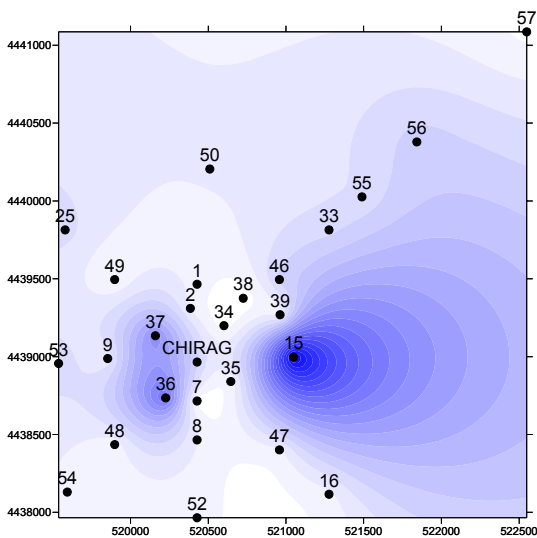
The average concentration of Pb was highest at station 25, 1000m northwest of Chirag. Higher average concentrations are present at stations 35, 15 and 37 in the centre of the survey area, with lower concentrations present at station 48, 54 and 52 to the extreme southwest, station 49, 750m northwest and stations 50, 56 and 57 to the extreme north and northeast.

**Table 5.2 Average Metal Concentrations ( $\mu\text{g}\cdot\text{g}^{-1}$ ) Chirag Survey 2010**

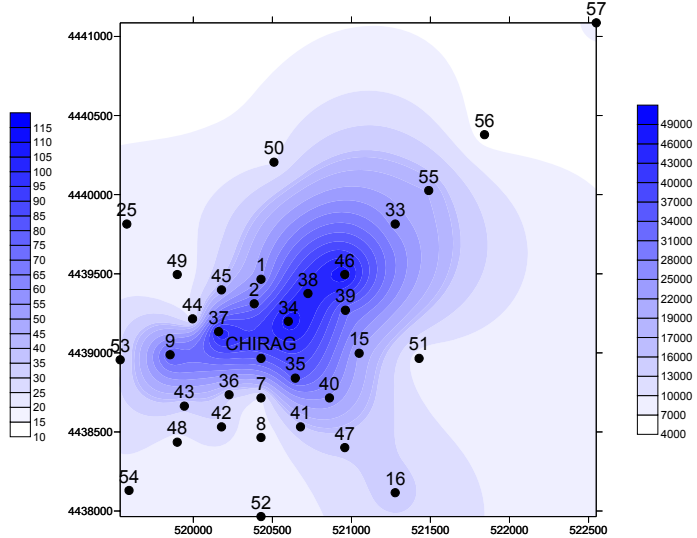
Station Number	As	Ba HNO <sub>3</sub>	Ba Fusion	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
1	18.2	21,349	24,460	0.83	28.0	19.3	19,992	0.04	406	27.2	50.9
2	18.9	23,010	31,218	0.58	34.1	19.7	22,858	0.03	439	24.7	61.4
7	12.4	8,644	9,454	0.25	61.2	41.3	33,625	0.04	638	24.0	186.2
8	20.2	6,340	7,776	0.25	34.2	23.7	23,730	0.04	572	21.1	90.2
9	21.5	27,170	34,870	0.78	44.3	23.0	29,032	0.05	433	28.5	74.8
15	117.9	18,827	21,544	0.48	51.9	33.0	59,115	0.05	547	33.3	101.6
16	18.6	9,595	14,276	0.36	37.6	26.9	22,523	0.06	607	28.8	58.6
25	27.2	9,204	9,894	0.32	52.8	25.2	32,484	0.05	522	48.0	72.1
33	28.6	19,726	23,726	0.56	39.8	19.9	30,069	0.05	433	25.3	60.8
34	13.0	21,393	48,257	0.67	57.6	25.0	27,967	0.03	467	30.4	93.7
35	16.2	27,062	35,474	0.59	42.8	28.3	26,604	0.05	525	37.7	99.5
36	71.4	9,763	14,025	0.42	46.7	17.4	38,693	0.03	488	20.5	65.8
37	58.8	24,323	46,141	0.75	42.2	35.9	39,988	0.03	467	33.4	117.4
38	12.3	30,627	45,299	0.68	58.4	27.1	26,519	0.05	459	28.1	83.5
39	17.9	27,374	32,106	0.58	33.1	18.1	23,160	0.03	371	26.4	53.4
40	NA	NA	24,706	NA	NA	NA	NA	NA	NA	NA	NA
41	NA	NA	15,457	NA	NA	NA	NA	NA	NA	NA	NA
42	NA	NA	12,998	NA	NA	NA	NA	NA	NA	NA	NA
43	NA	NA	13,779	NA	NA	NA	NA	NA	NA	NA	NA
44	NA	NA	9,661	NA	NA	NA	NA	NA	NA	NA	NA
45	NA	NA	18,110	NA	NA	NA	NA	NA	NA	NA	NA
46	31.8	24,327	48,809	0.71	54.0	23.0	27,938	0.05	569	27.1	73.5
47	18.7	9,716	13,685	0.35	45.8	23.3	25,324	0.06	610	25.7	71.3
48	17.0	8,292	9,077	0.30	46.7	21.4	26,407	0.05	433	17.2	62.8
49	14.9	6,916	7,553	0.22	49.1	19.4	26,371	0.03	504	15.8	56.5
50	20.8	8,513	9,768	0.30	50.9	17.4	30,010	0.04	529	16.7	58.5
51	NA	NA	8,072	NA	NA	NA	NA	NA	NA	NA	NA
52	17.3	4,755	7,169	0.23	48.2	16.9	24,707	0.03	471	15.3	50.4
53	28.0	11,127	11,843	0.35	52.1	19.0	33,215	0.04	548	21.0	63.3
54	19.9	8,081	9,864	0.36	48.0	18.7	31,127	0.03	473	16.2	54.8

Table 5.2 (Continued) Average Metal Concentrations ( $\mu\text{g.g}^{-1}$ ) Chirag Survey 2010

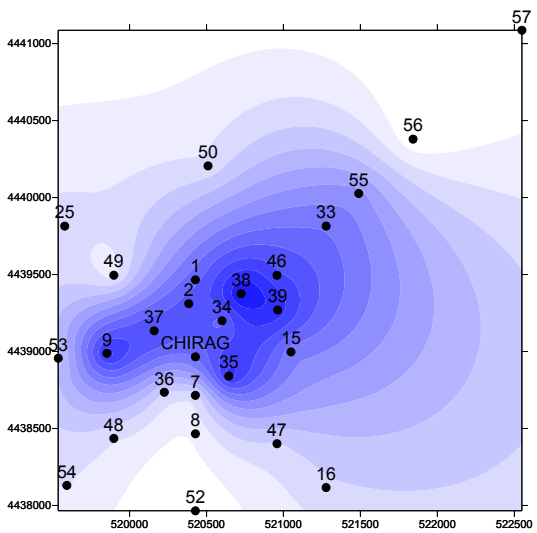
Station Number	As	Ba HNO <sub>3</sub>	Ba Fusion	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
55	26.1	16,796	18,838	0.56	34.3	16.7	25,342	0.04	431	26.3	54.0
56	32.5	4,297	5,656	0.20	66.5	22.1	36,719	0.05	718	18.7	78.0
57	13.6	5,195	7,312	0.22	64.9	22.8	31,814	0.05	552	17.8	69.0



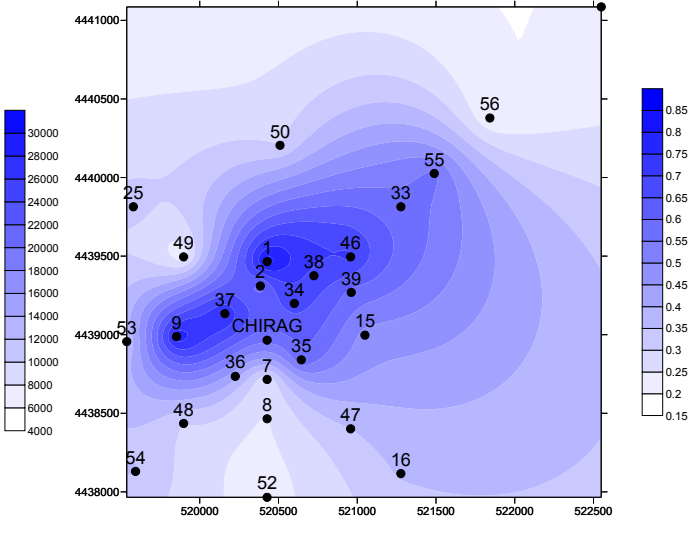
As 2010



Ba Fusion 2010

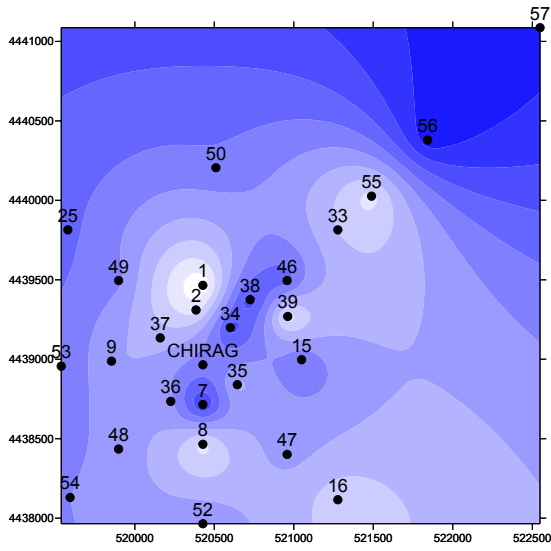


Ba HNO<sub>3</sub> 2010

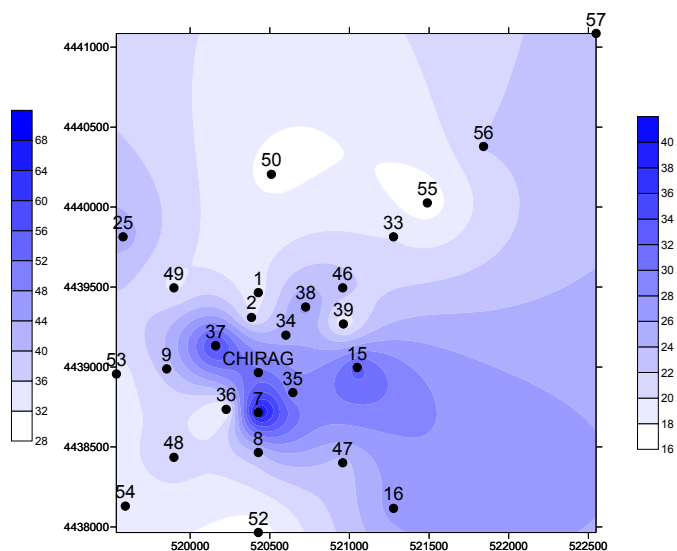


Cd 2010

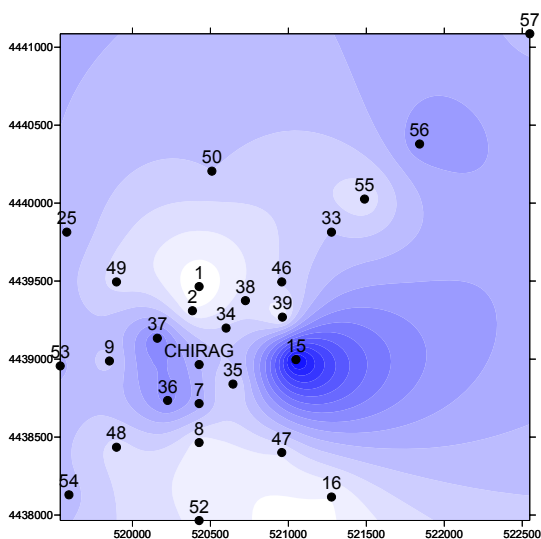
Figure 5.2 Contour Plots Average Trace Metal Concentrations ( $\mu\text{g.g}^{-1}$ ) Chirag Survey 2010



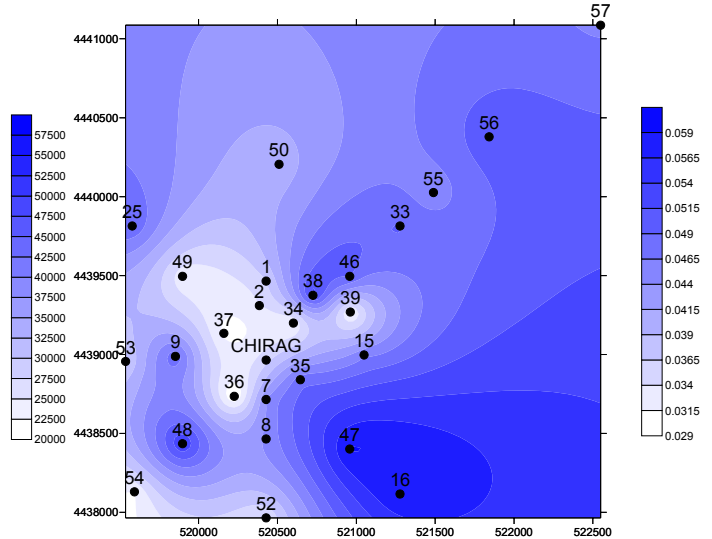
Cr 2010



Cu 2010



Fe 2010

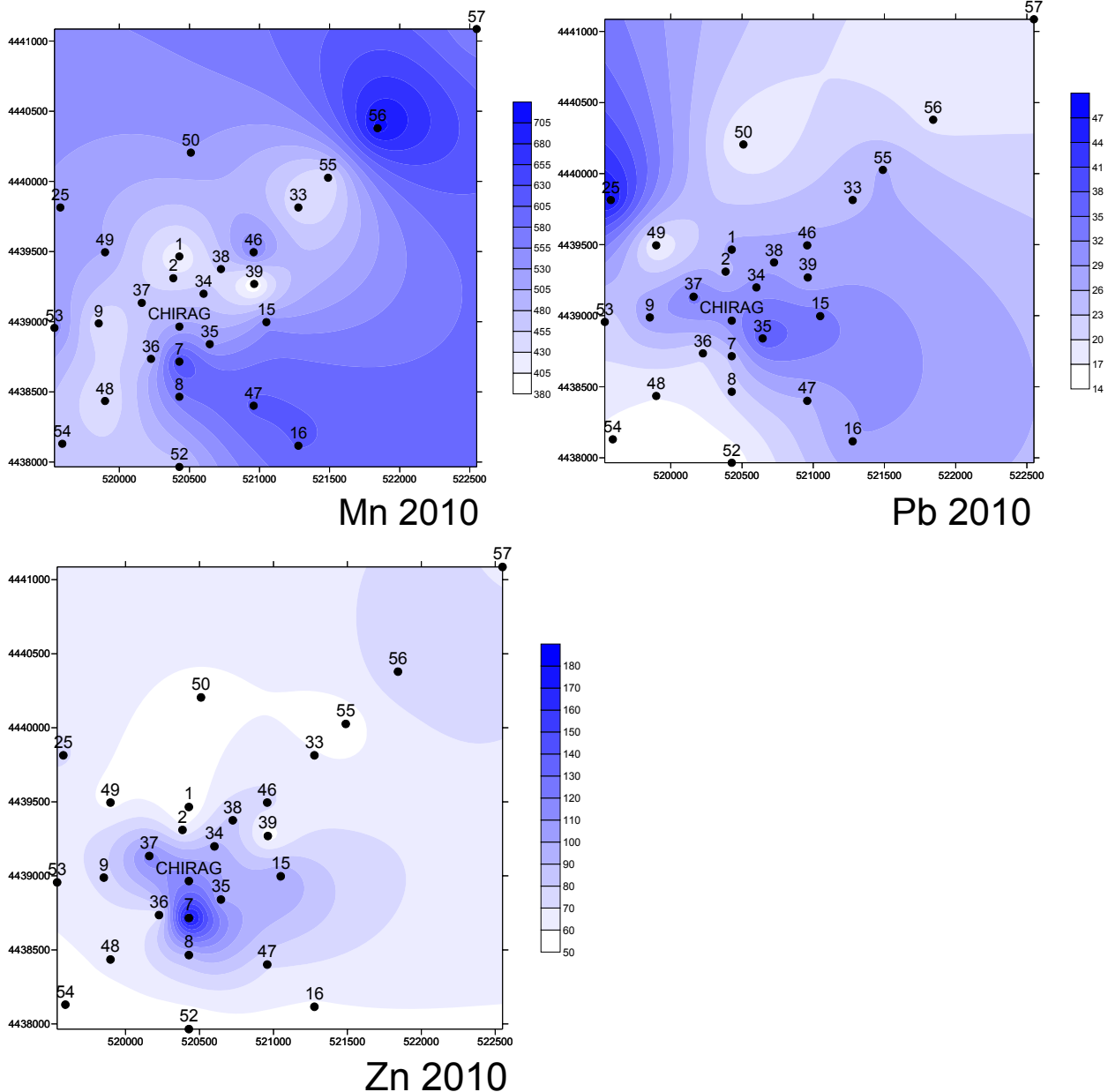


Hg 2010

Figure 5.2 (Continued)  
Chirag Survey 2010

Contour Plots Average Trace Metal Concentrations ( $\mu\text{g}\cdot\text{g}^{-1}$ )





**Figure 5.2 (Continued) Contour Plots Average Trace Metal Concentrations ( $\mu\text{g}\cdot\text{g}^{-1}$ ) Chirag Survey 2010**

## 5.2. Relationship between Trace Metals

The relationship between elements was tested by a Pearson's  $r$  correlation analysis of replicate values, the results are presented in table 5.3. Selected paired variable scatter plots are given in figure 5.3.

High correlation coefficients exceeding 0.80 have been given between both extracted forms of Ba and Cd. The paired variable scatter plot indicates that the correlation is strongest in samples where the Ba concentration is  $<20,000\mu\text{g}\cdot\text{g}^{-1}$ . As Ba concentrations exceed this level a wide scatter is present and the Cd concentration plateaus at  $0.60$  to  $0.80\mu\text{g}\cdot\text{g}^{-1}$ . This feature was also observed in 2008.



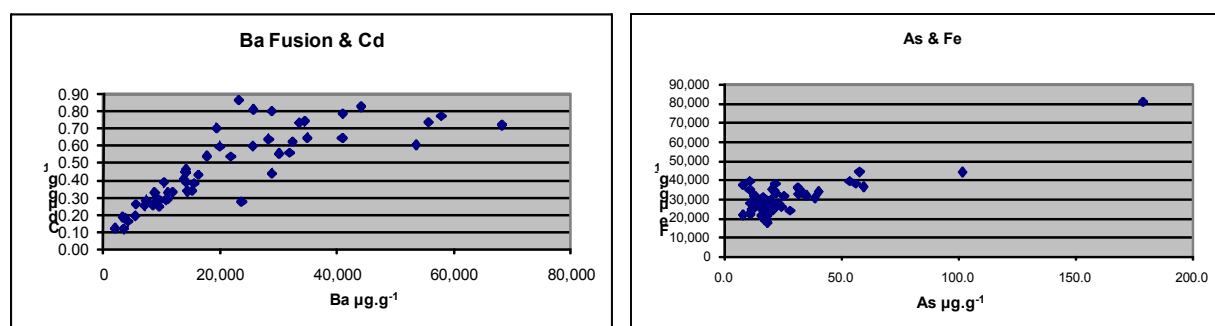
A relationship between Ba and Cd has been identified in a number of ACG surveys, these include Regional studies outside the influence of operational activities and baseline studies carried out prior to operational activities have taken place, suggesting that this relationship is a natural characteristic of Caspian sediments. As total Ba (fusion) also takes account of barite from drilling discharges, the loss of relationship at the highest Ba (fusion) concentrations may be due to the presence of additional barite from drilling discharges which will not have the underlying Ba-Cd relationship.

A high correlation coefficient of 0.84 has been given between Fe and As. The scatter plot indicate the result is being driven by a small number of samples where concentrations of both variables are higher, and that overall the variables are independent with no relationships being present.

Mn has been correlated with Cr (06.0) and Zn with Cu (0.83). Weaker correlations of 0.51 to 0.53 have also been indicated between Cr and Fe and for Cu with Fe and Mn.

**Table 5.3 Pearson's r Correlation between Replicate Metal Concentrations; Chirag Survey 2010**

	As	Ba HNO <sub>3</sub>	Ba Fusion	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
As	1.00										
Ba HNO <sub>3</sub>	0.09	1.00									
Ba Fusion	0.08	0.79	1.00								
Cd	0.04	0.86	0.81	1.00							
Cr	0.06	-0.28	-0.07	-0.37	1.00						
Cu	0.29	0.09	0.26	0.00	0.46	1.00					
Fe	0.84	-0.07	-0.01	-0.18	0.53	0.52	1.00				
Hg	0.03	0.02	-0.03	-0.11	0.21	0.40	0.10	1.00			
Mn	0.18	-0.38	-0.25	-0.45	0.60	0.51	0.43	0.44	1.00		
Pb	0.17	0.46	0.36	0.35	-0.04	0.31	0.15	0.21	-0.04	1.00	
Zn	0.22	0.08	0.21	-0.03	0.41	0.83	0.45	0.19	0.41	0.28	1.00



**Figure 5.3 Paired Variable Scatter Plots**

### 5.1. Comparison to Previous Chirag Survey Data

Table 5.4 below gives the range and mean replicate metal concentrations from the 2000, 2004, 2006, 2008 and 2010 surveys and table 5.4 gives the comparable average trace metal concentrations at each station.

The maximum As concentration has fluctuated between years and is high in relation to the median and mean values, which have remained low and generally comparable between years.

The range, median and mean Ba (fusion) concentration was highest in 2004 with lower, comparable concentrations being observed on subsequent surveys.

Other than the lower Cd concentrations in 2004, the range mean and median results for Cd, Cr and Cu are similar on all surveys.

The maximum Fe concentration has fluctuated between years and will likely be the result of varying presence of the arseno-ferrous mineral described above.

Hg concentrations have fluctuated between years, with the highest maximum median and mean being observed in 2004. The maximum concentration observed in 2010 is within the maximum recorded in both the 2000 and 2004 surveys.

The variation between Mn concentrations has reduced on each consecutive survey. Despite this the median and mean concentrations have remained similar on all surveys.

The maximum concentration of Pb was highest in 2010. Median and mean results are very similar for all surveys with the exception of 2008, which observed a lower maximum, median and mean.

Zinc results have fluctuated between years. The results from 2010 are very similar to those recorded in 2000, with the highest maximum, median and mean concentrations being present.

**Table 5.4 Replicate Trace Metal Range, Median & Mean Chirag 2000, 2004, 2006, 2008 & 2010  $\mu\text{g.g}^{-1}$**

		As	Ba HNO <sub>3</sub>	Ba fusion	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
Min	2010	8.2	1,740	2,025	0.11	21.7	12.1	17,119	0.02	324	11.0	37.0
	2008	8.3	1,240	570	0.14	18.2	9.2	14,900	0.01	206	11.4	26.4
	2006	5.6	1,370	4,900	0.01	4.5	4.7	3,400	0.02	67	4.1	7.1
	2004	14.0	464	4,150	0.10	23.7	12.0	14,175	0.01	NA	13.7	31.6
	2000	NA	311	NA	NA	18.5	8.3	13,050	0.01	NA	6.9	23.6
Max	2010	179.3	33,773	68,233	0.86	90.6	52.9	80,544	0.08	768	75.2	224.7
	2008	92.8	22,700	59,600	0.84	68.2	38.6	58,300	0.05	1,131	26.9	90.8
	2006	224.1	31,700	70,100	0.81	83.2	43.0	92,000	0.05	3,065	35.2	172.1
	2004	133.7	31,100	122,000	0.42	88.3	48.3	79,215	0.15	NA	32.3	99.3
	2000	NA	14,910	NA	NA	97.8	41.0	80,605	0.09	NA	40.4	271.1
Med	2010	19.2	13,431	15,517	0.43	46.1	21.3	28,154	0.04	485	24.4	67.2
	2008	17.7	7,930	9,015	0.46	42.5	22.3	27,400	0.03	405	16.2	58.3
	2006	18.2	11,400	14,700	0.44	42.7	25.6	31,900	0.03	438	20.2	60.8
	2004	21.7	6,705	20,850	0.19	42.6	20.1	22,944	0.07	NA	22.0	50.1
	2000	NA	6,538	NA	NA	43.6	21.0	28,850	0.03	NA	22.7	71.4
Mean	2010	27.4	15,093	19,724	0.46	47.1	23.3	29,820	0.04	508	25.2	75.5
	2008	21.6	9,587	13,015	0.48	44.1	22.2	28,258	0.03	455	16.6	57.4
	2006	29.6	13,358	19,066	0.43	46.0	25.6	33,070	0.03	506	21.3	65.0
	2004	30.6	7,853	26,389	0.21	43.7	21.1	25,958	0.07	NA	22.4	55.9
	2000	NA	7,160	NA	NA	43.8	21.5	31,064	0.03	NA	22.8	74.6

**Table 5.4 (Continued) Replicate Trace Metal Range, Median & Mean Chirag 2000, 2004, 2006, 2008 & 2010  $\mu\text{g.g}^{-1}$**

		As	Ba HNO <sub>3</sub>	Ba fusion	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
CV	2010	98.6	59	72	46	29	35	32	27	22	38	42
	2008	66.0	61	94	40	33	28	30	30	33	20	26
	2006	115.0	60	74	43	40	31	43	25	69	28	42
	2004	91.0	73	90	32	28	36	47	47	NA	20	34
	2000	NA	57	NA	NA	31	28	41	41	NA	26	47

Table 5.5 below gives the average concentrations at each station recorded in 2004, 2006, 2008 and 2010.

The high median and mean total Ba concentration in 2004 was influenced by the very high concentrations at stations 34 and 39, located to the NE of the platform. Concentrations at these positions although remaining relatively high, were lower in the subsequent surveys. The only notable increase in concentration between 2004 and 2006 was observed at stations 2 and 37 located to the north and northeast of the Chirag position.

The greatest increase in Ba concentrations between 2008 and 2010 were observed at stations 38 and 46 where the 2010 concentrations exceeded  $40,000\mu\text{g.g}^{-1}$  and are around double the previously recorded concentrations at these positions. These stations lie to the north of stations 34 and 39, where the highest historical concentrations have been recorded.

There has been generally little change with regard to the concentrations of Cu, Cr, Hg, Fe and Mn.

Variation has been observed in the concentration of Pb at a number of stations between 2006 and 2010, with concentrations reducing in 2008 and increasing in 2010. The majority of stations where this has been observed have concentrations in 2010 similar to those observed in 2008. However, the concentrations recorded in 2010 at stations 25 ( $48\mu\text{g.g}^{-1}$ ) and 35 ( $37.7\mu\text{g.g}^{-1}$ ) exceed the previously recorded levels. Station 35 is located directly to the southeast of the platform, whereas station 25 is located 1000m to the northwest.

The zinc concentration has increased on each consecutive survey from 2006 at station 35 and from 2008 at stations 7 and 8. Higher concentrations were recorded at a number of stations in 2010, particularly stations 7, 8, 15, 25, 35 and 47, where the average concentrations exceed the previously recorded maximums at these positions. However, as noted in table 5.4 all concentrations recorded are within the maximum recorded in 2000.

**Table 5.5 Trace Metal Concentrations Chirag Survey 2004, 2006, 2008 & 2010  $\mu\text{g}\cdot\text{g}^{-1}$**

Station	As				Ba HNO3			
	2004	2006	2008	2010	2004	2006	2008	2010
1	18.7	16.0	13.6	18.2	6,335	21,950	16950	21,349
2	25.1	47.4	23.3	18.9	6,890	30,150	16200	23,010
7	31.9	25.7	10.0	12.4	3,230	12,550	2075	8,644
8	17.8	13.7	15.1	20.2	7,955	4,880	7510	6,340
9	22.1	23.4	18.5	21.5	5,855	16,200	15450	27,170
15	23.6	25.0	28.0	117.9	6,075	21,750	8410	18,827
16	NA	18.7	12.9	18.6	6,135	10,580	3550	9,595
25	NA	51.8	26.0	27.2	16,250	15,700	4325	9,204
33	31.0	50.4	24.2	28.6	7,235	18,300	13340	19,726
34	21.5	16.8	12.0	13.0	5,455	30,050	10040	21,393
35	19.8	15.7	17.9	16.2	5,610	21,750	17700	27,062
36	22.8	17.9	33.0	71.4	9,110	10,600	8670	9,763
37	132.6	131.5	41.5	58.8	5,095	15,700	19300	24,323
38	NA	13.5	14.4	12.3	11,750	18,350	16500	30,627
39	NA	16.6	15.3	17.9	30,050	30,050	18200	27,374
40	NA	7.9	NA	NA	14,300	7,520	NA	NA
41	NA	116.3	NA	NA	9,540	11,020	NA	NA
42	NA	27.2	NA	NA	1,067	4,920	NA	NA
43	NA	17.8	NA	NA	4,675	16,250	NA	NA
44	NA	10.9	NA	NA	1,915	9,700	NA	NA
45	NA	8.2	NA	NA	8,230	8,895	NA	NA
46	25.5	24.3	39.2	31.8	8,910	4,300	14050	24,327
47	14.5	49.9	13.2	18.7	9,830	11,450	7285	9,716
48	17.6	17.7	21.8	17.0	9,860	10,600	7215	8,292
49	20.6	17.6	18.3	14.9	9,950	8,485	3365	6,916
50	NA	27.2	67.0	20.8	7,090	13,750	5710	8,513
51	NA	11.1	NA	NA	3,575	4,830	NA	NA
52	NA	13.1	15.5	17.3	1,621	2,425	4365	4,755
53	NA	38.3	25.0	28.0	2,600	6,245	4530	11,127
54	45.3	59.6	20.0	19.9	9,405	7,655	7100	8,081
55	NA	17.6	11.5	26.1	NA	18,700	9700	16,796
56	NA	21.0	14.0	32.5	NA	14,135	1833	4,297
57	NA	5.9	10.6	13.6	NA	1,385	5880	5,195

**Table 5.5 (Continued) Trace Metal Concentrations Chirag Survey 2004, 2006, 2008 & 2010  $\mu\text{g}\cdot\text{g}^{-1}$** 

Station	Ba fusion				Cd			
	2004	2006	2008	2010	2004	2006	2008	2010
1	27,300	32,450	28200	24,460	0.22	0.06	0.69	0.83
2	22,400	62,850	17000	31,218	0.22	0.65	0.70	0.58
7	9,500	15,750	2210	9,454	0.23	0.48	0.25	0.25
8	14,650	7,510	7900	7,776	0.12	0.30	0.46	0.25
9	17,000	18,700	20500	34,870	0.17	0.52	0.76	0.78
15	26,050	23,700	8890	21,544	0.22	0.78	0.63	0.48
16	11,900	12,150	4250	14,276	NA	NA	0.44	0.36
25	35,100	21,850	5985	9,894	NA	NA	0.51	0.32
33	20,050	23,500	16500	23,726	0.23	0.67	0.60	0.56
34	114,000	30,600	58550	48,257	0.40	0.73	0.63	0.67
35	27,100	16,750	28600	35,474	0.20	0.52	0.74	0.59
36	21,300	12,950	9085	14,025	0.19	0.39	0.41	0.42
37	28,050	64,650	37200	46,141	0.28	0.25	0.59	0.75
38	21,850	24,250	20300	45,299	NA	0.52	0.74	0.68
39	93,950	37,750	26700	32,106	NA	0.45	0.69	0.58
40	55,350	10,700	12180	24,706	NA	NA	NA	NA
41	31,900	14,200	8130	15,457	NA	NA	NA	NA
42	6,755	11,150	3105	12,998	NA	NA	NA	NA
43	20,230	21,250	6555	13,779	NA	NA	NA	NA
44	5,865	13,800	6685	9,661	NA	NA	NA	NA
45	17,300	10,631	11450	18,110	NA	NA	NA	NA
46	11,750	8,660	14450	48,809	0.18	0.39	0.37	0.71
47	15,250	12,450	9700	13,685	0.18	0.39	0.40	0.35
48	13,300	14,750	9075	9,077	0.21	0.44	0.30	0.30
49	13,825	11,700	4480	7,553	0.14	0.34	0.19	0.22
50	23,850	14,000	7175	9,768	NA	NA	0.27	0.30
51	21,300	6,150	7470	8,072	NA	NA	NA	NA
52	17,555	5,900	4600	7,169	NA	NA	0.33	0.23
53	14,235	7,165	5960	11,843	NA	NA	0.29	0.35
54	33,000	9,365	7900	9,864	0.18	0.37	0.41	0.36
55	NA	21,250	10340	18,838	NA	0.48	0.44	0.56
56	NA	22,600	2045	5,656	NA	0.11	0.16	0.20
57	NA	8,060	6310	7,312	NA	0.28	0.43	0.22

**Table 5.5 (Continued) Trace Metal Concentrations Chirag Survey 2004, 2006, 2008 & 2010  $\mu\text{g}\cdot\text{g}^{-1}$**

Station	Cr				Cu			
	2004	2006	2008	2010	2004	2006	2008	2010
1	41.1	33.1	36.3	28.0	17.0	28.6	24.1	19.3
2	45.8	54.6	47.9	34.1	23.8	37.1	27.5	19.7
7	28.7	23.9	67.4	61.2	24.6	17.6	30.0	41.3
8	39.5	11.7	34.4	34.2	16.7	8.6	20.4	23.7
9	48.5	53.6	31.4	44.3	19.9	25.4	20.1	23.0
15	36.5	32.9	34.4	51.9	35.2	22.8	18.3	33.0
16	NA	24.3	33.3	37.6	NA	16.7	18.9	26.9
25	NA	28.9	31.7	52.8	NA	19.5	22.7	25.2
33	35.4	40.9	29.4	39.8	15.9	25.5	15.7	19.9
34	49.9	53.7	43.8	57.6	33.0	35.7	23.4	25.0
35	27.2	44.1	37.9	42.8	12.1	25.3	24.0	28.3
36	53.9	73.3	52.0	46.7	23.4	33.0	20.5	17.4
37	57.7	60.2	22.9	42.2	21.4	31.7	12.5	35.9
38	NA	35.9	57.2	58.4	NA	20.6	29.0	27.1
39	NA	69.7	27.6	33.1	NA	40.6	19.0	18.1
40	NA	46.1	NA	NA	NA	25.7	NA	NA
41	NA	40.1	NA	NA	NA	27.7	NA	NA
42	NA	60.1	NA	NA	NA	25.7	NA	NA
43	NA	23.7	NA	NA	NA	11.4	NA	NA
44	NA	50.5	NA	NA	NA	26.8	NA	NA
45	NA	50.9	NA	NA	NA	24.8	NA	NA
46	68.5	56.0	54.9	54.0	23.5	29.7	22.2	23.0
47	41.5	40.6	36.6	45.8	20.3	27.8	21.9	23.3
48	38.8	38.7	46.7	46.7	15.8	25.9	26.8	21.4
49	44.1	48.4	59.3	49.1	16.6	26.3	30.9	19.4
50	NA	20.6	49.9	50.9	NA	12.2	18.7	17.4
51	NA	70.1	NA	NA	NA	33.2	NA	NA
52	NA	67.5	42.1	48.2	NA	32.4	16.4	16.9
53	NA	76.1	60.4	52.1	NA	35.1	21.4	19.0
54	41.8	36.1	42.6	48.0	17.8	23.1	24.6	18.7
55	NA	28.6	53.5	34.3	NA	14.9	21.5	16.7
56	NA	40.3	60.5	66.5	NA	20.2	24.5	22.1
57	NA	82.2	53.8	64.9	NA	33.8	22.6	22.8

**Table 5.5 (Continued) Trace Metal Concentrations Chirag Survey 2004, 2006, 2008 & 2010  $\mu\text{g}\cdot\text{g}^{-1}$**

Station	Fe				Hg			
	2004	2006	2008	2010	2004	2006	2008	2010
1	17,507	22,000	21500	19,992	0.086	0.030	0.043	0.036
2	24,914	38,100	29550	22,858	0.075	0.034	0.028	0.034
7	26,793	22,600	34500	33,625	0.034	0.026	0.032	0.044
8	18,434	9,900	22250	23,730	0.111	0.018	0.041	0.045
9	24,329	32,400	21800	29,032	0.091	0.029	0.033	0.048
15	21,288	25,800	28250	59,115	0.107	0.030	0.030	0.046
16	NA	20,050	20400	22,523	NA	0.020	0.026	0.059
25	NA	39,900	23050	32,484	NA	0.037	0.028	0.049
33	25,683	38,650	22200	30,069	0.089	0.033	0.036	0.049
34	25,131	29,850	20650	27,967	0.068	0.023	0.024	0.031
35	16,720	26,950	22850	26,604	0.034	0.018	0.048	0.048
36	32,164	39,350	34650	38,693	0.016	0.020	0.025	0.029
37	46,769	76,500	25900	39,988	0.063	0.026	0.018	0.031
38	NA	21,950	31000	26,519	NA	0.022	0.042	0.053
39	NA	35,500	17350	23,160	NA	0.033	0.020	0.031
40	NA	25,800	NA	NA	NA	0.021	NA	NA
41	NA	57,800	NA	NA	NA	0.017	NA	NA
42	NA	36,250	NA	NA	NA	0.024	NA	NA
43	NA	17,000	NA	NA	NA	0.023	NA	NA
44	NA	37,300	NA	NA	NA	0.016	NA	NA
45	NA	26,050	NA	NA	NA	0.026	NA	NA
46	33,547	27,600	41800	27,938	0.052	0.021	0.031	0.049
47	17,505	36,900	21600	25,324	0.117	0.038	0.044	0.059
48	19,145	26,900	28400	26,407	0.081	0.035	0.036	0.054
49	23,049	32,350	33950	26,371	0.042	0.027	0.042	0.032
50	NA	22,500	50350	30,010	NA	0.025	0.034	0.040
51	NA	33,550	NA	NA	NA	0.029	NA	NA
52	NA	37,050	25250	24,707	NA	0.024	0.023	0.034
53	NA	59,750	35800	33,215	NA	0.029	0.024	0.036
54	42,353	41,550	29950	31,127	0.083	0.026	0.023	0.031
55	NA	22,300	27900	25,342	NA	0.022	0.045	0.045
56	NA	30,650	34600	36,719	NA	0.019	0.037	0.051
57	NA	40,500	29200	31,814	NA	0.033	0.030	0.046



**Table 5.5 (Continued) Trace Metal Concentrations Chirag Survey 2004, 2006, 2008 & 2010  $\mu\text{g}\cdot\text{g}^{-1}$**

Station	Mn			Pb			
	2006	2008	2010	2004	2006	2008	2010
1	374	365	406	24.1	26.6	22.9	27.2
2	412	366	439	19.6	32.1	18.0	24.7
7	310	689	638	20.0	23.0	15.3	24.0
8	205	445	572	22.4	11.5	17.2	21.1
9	544	365	433	23.5	20.2	16.9	28.5
15	482	371	547	27.4	27.7	16.6	33.3
16	478	363	607	NA	25.0	14.8	28.8
25	474	283	522	NA	21.9	13.4	48.0
33	409	347	433	21.3	26.8	14.8	25.3
34	384	324	467	26.1	27.8	16.8	30.4
35	405	404	525	25.6	18.8	24.3	37.7
36	709	524	488	20.2	17.5	16.2	20.5
37	494	313	467	26.2	34.0	17.6	33.4
38	369	402	459	NA	23.0	20.8	28.1
39	308	348	371	NA	25.0	15.4	26.4
40	455	NA	NA	NA	17.5	NA	NA
41	1735	NA	NA	NA	24.4	NA	NA
42	464	NA	NA	NA	17.4	NA	NA
43	380	NA	NA	NA	17.0	NA	NA
44	469	NA	NA	NA	20.0	NA	NA
45	439	NA	NA	NA	15.7	NA	NA
46	626	489	569	18.6	11.9	16.8	27.1
47	596	467	610	25.0	26.1	17.4	25.7
48	382	417	433	18.1	17.9	16.5	17.2
49	463	528	504	16.6	17.3	13.7	15.8
50	361	830	529	NA	23.1	18.0	16.7
51	585	NA	NA	NA	16.5	NA	NA
52	721	505	471	NA	14.6	14.2	15.3
53	616	593	548	NA	19.5	14.8	21.0
54	375	448	473	24.0	20.7	13.3	16.2
55	366	473	431	NA	27.3	16.5	26.3
56	485	673	718	NA	21.0	15.1	18.7
57	826	491	552	NA	15.4	13.6	17.8

**Table 5.5 (Continued) Trace Metal Concentrations Chirag Survey 2004, 2006, 2008 & 2010**  
 $\mu\text{g}\cdot\text{g}^{-1}$

Station	Zn			
	2004	2006	2008	2010
1	52.3	56.6	54.9	50.9
2	58.8	96.8	64.3	61.4
7	56.9	43.5	70.8	186.2
8	43.4	19.6	52.2	90.2
9	47.1	66.3	47.1	74.8
15	53.8	57.6	50.1	101.6
16	NA	40.8	41.3	58.6
25	NA	50.1	39.3	72.1
33	45.2	65.4	45.9	60.8
34	97.3	80.6	70.1	93.7
35	34.8	58.0	81.4	99.5
36	64.1	82.9	58.7	65.8
37	93.7	103.6	40.9	117.4
38	NA	57.1	74.6	83.5
39	NA	171.9	41.7	53.4
40	NA	57.0	NA	NA
41	NA	60.0	NA	NA
42	NA	69.4	NA	NA
43	NA	28.4	NA	NA
44	NA	56.6	NA	NA
45	NA	66.7	NA	NA
46	66.8	60.4	76.3	73.5
47	46.2	59.6	51.1	71.3
48	39.7	57.0	62.8	62.8
49	42.4	63.4	61.0	56.5
50	NA	33.4	60.9	58.5
51	NA	71.8	NA	NA
52	NA	78.1	49.5	50.4
53	NA	90.0	64.0	63.3
54	52.4	54.2	46.2	54.8
55	NA	43.0	59.0	54.0
56	NA	52.6	70.6	78.0
57	NA	91.9	57.1	69.0

## 5.2. Trace Metal Summary

The concentrations of trace metals varied between stations and were generally similar to those recorded in 2008.

Concentrations of Ba and Cd were highest at stations directly to the west, north and northeast of the platform. As was the case in 2006 and 2008 a linear relationship was evident between these elements which became less apparent in samples where the concentrations were greatest, which may indicate the presence of barite from drilling discharges.

High concentrations of As and Fe were recorded in three samples, which will likely be due to the presence of an arseno-ferrous mineral which has been previously detected at this location.